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Building Energy Analysis — A Look into the Future

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Reprinted from
Third International Congress on Building Energy Management, ICBEM '87
Lausanne, Switzerland, Sept. 28 - Oct. 2, 1987
Vol. I, p. 90-101
(IRC Paper No. 1521)

Price $3.00

NRCC 28786

Canada

RÉSUMÉ

L'auteur décrit les récents développements et les tendances à venir concernant les outils de conception et les techniques d'analyse énergétique du bâtiment en se basant sur des articles présentés à la session "planification et outils de conception du bâtiment" du ICBEM 1987. Les articles traitent à la fois des outils détaillés et des outils simplifiés, ainsi que de leur utilisation dans l'analyse des stratégies de conservation d'énergie et l'élaboration de lignes directrices plus simples concernant la conservation d'énergie. Des articles relatifs aux études de cas sur les économies d'énergie de même que l'interaction des occupants sont également résumés.

91-01600/

BUILDING ENERGY ANALYSIS - A LOOK INTO THE FUTURE

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ABSTRACT

Recent developments and future trends in building energy analysis techniques and design tools are discussed in light of papers presented at ICBEM'87 session on Building Planning and Design Tools. The presentations cover both detailed and simplified tools, and their use in the analysis of energy conservation strategies and the development of simpler energy conservation guidelines. Presentations related to case studies on energy savings in practice, as well as occupant interaction, are also summarized.

1. THE NEED FOR ENERGY ANALYSIS

For the past few decades, there has been considerable interest in modeling and analysis of the thermal behaviour of buildings, in order to estimate their energy requirements as well as to permit sizing appropriate heating and cooling systems to maintain thermal comfort. Although a number of early manual methods are still in use, computerized methods introduced in the past twenty years have steadily increased in availability, complexity, speed, flexibility and more recently (due to the introduction of microcomputers), ease of use.

Initially inspired by a research drive to gain better understanding of a particular thermal problem, energy analysis and modeling have led to recommendations and guidelines for construction practice, insulation standards, energy conservation measures and novel designs of energy systems (1).

Despite fluctuations in energy prices, the use of energy analysis (or design tools)* continues to be a valuable asset for architects, engineers and designers, to narrow the range of possible solutions to a particular problem. Once a set of options is chosen, an analysis or a design tool can be used to evaluate and compare these design alternatives, in terms of their energy conservation potential, impact on the indoor environment and cost effectiveness.

In countries such as Canada where government programs are established to promote the construction of low energy buildings, the eligibility for funds under these programs is usually based on a maximum allowable energy consumption. Therefore, energy calculation methods are needed to determine the eligibility of proposed designs or their compliance with an energy standard.

* An energy analysis may or may not constitute a 'design tool'. This depends upon whether or not it is flexible, fast, easy and accurate enough to use at the early stage of design, when it is most effective.

Extrait de "The Third International Congress on Building Energy Management" Vol. I, © Presses polytechniques romandes, 1015 Lausanne, Suisse

Another important aspect of analysis and design tools is the education they offer the designer. Repeated use allows the designer to develop an intuitive sense of applicable energy design options. Eventually, decisions can be made based on past experience, reducing the need to evaluate many design options, and allowing one to concentrate on the most promising ones.

Many practitioners, however, admit that they use energy analysis only in the final stages of design to document the impact of the design. Few use energy analysis effectively early on, when the cost of changing a design decision is still small. This may indicate that most available energy analysis tools are not "design tools", or are not in a form that can be used at the conceptual design phase.

There are many uses for building energy analysis at different stages during building design and operation. Each one may demand a different type or class of analysis with a different combination of performance criteria. The design process involves many players, including owners, architects, engineers and builders. One might ask, what types of design tools are available and what properties must they possess to facilitate this process? What are the problems with existing tools and what are the future trends for energy analysis tools? What are they used for now and what are they to be used for in the future?

This paper attempts to answer some of these questions in light of the papers presented in this Session on Building Planning and Design Tools. The session includes 63 papers, divided into four sub-topics:

1. Design tools,
2. Theory and analysis of energy saving strategies,
3. Energy savings in practice,
4. Building concepts for hot climates.

Topics 1 to 3 are addressed in the above order to focus on the development of design tools, their characteristics and differences, followed by presentation and discussion of examples where they are used to analyse energy saving strategies, and finally an overview of practical cases of energy savings in buildings. Since building design concepts for hot climates are addressed by Dr. Givoni in his Keynote presentation, the last topic will not be covered in this paper.

2. ENERGY ANALYSIS AND DESIGN TOOLS

Currently available analysis and design tools may be divided into two categories: simplified methods and detailed methods.

2.1 Detailed Energy Analysis

This is the most flexible analysis technique for dynamic simulation of the thermal performance of a building and due to complexity of the calculation, usually requires a computer. It is a powerful technique, particularly suited for research applications in which the objective is to study a phenomenon in detail or to extrapolate experimental data to produce more generalized conclusions. The complex calculations, however, require a great deal of input data regarding the building components and the climate in which the building is to be operated.

The proliferation and advances of microcomputers in the past few years have brought complex computer energy analysis closer to the design stage. However, this is still limited by the complexity of the required input data. An excellent review of the characteristics required of computer thermal analysis as a design tool was given by Sondregger (2) who suggested, correctly, that parametric studies are poor substitutes for the real power of computers, the ability to ask "what if" with regard to different design alternatives and see the answer on the screen quickly. This may be achievable in the near future through the integration of a thermal modeling technique, a general building and systems database, and an expert system as the interface between the computer and the designer.

In the domain of detailed composite modeling, a number of analysis techniques are widely used (3). These include network or nodal analysis, response factor techniques, and frequency domain techniques. Neirac* presents a method to reduce the complexity of solution of nodal thermal analysis through the reduction of the number of nodes. Nodes are grouped numerically (through linear regression) to reduce the model order. This results in a much faster solution with a slight reduction in accuracy. Higgs examines the effect on the results produced by the large thermal analysis program "DEROB", of decreasing the time step and increasing the nodal representation of building components. He finds that decreasing the time steps is not sufficiently repaid by the increase in accuracy. However, liberal use of nodes is warranted. It is worth noting that most of the improvement is achieved when 5 nodes are used instead of 2 (for a high-mass wall). Further increase to 8 nodes does not add any significant improvement. This, of course, will increase the computation time.

The paper by Roux et al. stresses the merits of the integration of the heating system analysis with the dynamic analysis of the building at the conceptional design stage. Such an integration permits the determination of the effect of different heating system strategies, including the system type and size, on energy consumption and comfort. The authors present a network analysis method "Bâtiment" and its application for a purely convective heating system, a hot water radiator system, and a hot water floor heating system.

Waters presents a methodology for modeling the thermal behaviour of industrial buildings. He emphasizes the importance of input parameter values, which in many cases do not represent reality.

Detailed thermal modeling is also used to analyse single building components, such as walls and windows, in order to predict the effect of various construction strategies on performance (thermal and hygric). An example is presented by Wright and Sullivan for glazing systems. The computer program "VISION" can model a variety of glazing designs such as low emissivity films, IR transparent glazings, and substitute fill gases, to determine their effects on heat transfer, solar gain, surface temperature, and hour-by-hour energy balance.

Lewis, using the dynamic model HTB2, examines whether the radiative/convective characteristics of the heat input and controls affect the impact of passive solar heating on auxilliary heating reduction.

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* Details of ICBEM papers may be found in the proceedings, they are not referenced in this paper.

Some building energy analysis models are built or modified to be used for a particular application. Molle presents a response factor model with particular emphasis on floor heating. The model is used to examine the performance of a floor heating system under different strategies for room temperature control and thermal insulation. An important conclusion is that floor heating is not preferred in combination with intermittent heating; this is supported by two other papers in this session dealing with thermal mass effect.

A good example of the use of detailed computer analysis in design is given by Lanz. A computer analysis (IGLOU-G) is used to examine the design of the new airport building in Stuttgart. Compromises were reached between the architecture design requirements and the energy and environmental performance of the building.

2.2 Simplified Energy Analysis

It is now generally accepted that detailed computer energy analysis is the most accurate and versatile representation of a building performance. This makes computer simulation a desirable design tool, provided it meets the other criteria of speed and ease of use. Since most of these models are still costly and time consuming, designers ask for simple techniques that can be used on desk-top microcomputers, calculators and sometimes even manually. Practical applications are generally not concerned with detailed modeling of a heat transfer process, but with obtaining quick answers to questions on design alternatives or satisfying the requirement of a building (energy) code. Simple methods may be accurate enough for these purposes and, therefore, are usually termed design tools, as long as they are easy to use, readily available and inexpensive to apply. Some compromise of accuracy and versatility has to be made to achieve the desired level of simplicity. However, the limitations to energy analysis are more often due to uncertainty of input data than to the calculation method itself.

Simple methods include analysis simplified by reducing the number of building components and zones to be handled (for example, single zone analysis with a thermal storage effect lumped in one or two nodes), and correlation methods where the effects of parameter variability are accounted for by simple correlation generated by multiple runs of a detailed analysis (4).

Examples of simple analyses are presented in the papers by Bianchi and Gilson, and by Matthews and Joubert. Both papers treat the building as a homogeneous isothermal body that can be represented by a simple RC electric analogue. Theoretically, the lumped parameter method is accurate if the ratio of the building thermal inertia to external thermal resistance is less than 0.1. The difficulty lies in determining the appropriate value for thermal inertia. The validity of the method does, however, increase with increasing the thermal insulation of the building envelope. Bianchi and Gilson use the technique to examine the energy saving due to intermittent heating systems. The average seasonal efficiency of the heating system is used in the analysis. The authors conclude that under the condition examined, intermittent heating in houses with the thermal inertia commonly used in Italy does not lead to larger energy savings, as had been expected.

Matthews and Joubert added an extra resistance to the circuit to account for natural ventilation. Empirical constants are used to represent the expected natural ventilation rate in typical South African buildings. The

method is then used to perform a study of naturally ventilated buildings to demonstrate the effect of changes to the design on the indoor air temperature and on the energy efficiency. The method includes empirically derived equations which may, however, render it very specific to the cases and climates studied.

Cammarata et al. outline the advantages in improving the computer code "BIOCLI", (a lumped parameter model) by including calculation of wall heat transfer using a distributed parameter model. They indicate that, compared to the original model, the generated model provides more accurate results and a deeper insight into the building physics, particularly for solar heated houses.

A simple energy analysis is presented by Lefebvre and Neveu. Method H2E uses a correlation between the heating requirement of a dwelling and the degree-hours (base 19°C), the gain-(solar and internal) to-load ratio and the building principle time constant. A method to calculate the time constant is also given. Method H2E takes into account two temperature control strategies: indoor temperature fixed at 19°C and a night setback to 15°C between 23h and 6h. The method is compared with a detailed computer energy analysis. Results agree to within 5% for large energy requirements. However, for low energy requirements, the difference is in the order of 20%. One source of error, according to the authors, is the calculation of useful solar and internal gains, which becomes a significant factor particularly for low energy buildings.

Extending Subbarao's (5) search for improved energy analysis tools, Smart and Ballinger's paper presents their preliminary attempts at predicting the dynamic performance of a passive solar house using actual performance data. The analysis is aimed at using a few simple parameters to describe the building thermal performance.

In a different application of thermal analysis, Shaviv presents a CAD tool for the determination of solar rights (the availability of solar insolation onto a proposed building). The method generates a nomogram of the envelope of all possible locations for neighboring buildings within an allowed height to enable insolation of a given passive collector for a specified period and time of day. The method is easy to use and can be implemented in the early design phase.

Energy analysis can also be used to generate the simplest form of design tools, that is, rules of thumb and guidelines. These are usually the most useful tools, particularly at the early stages of design when the details of the building are still being determined.

Canha Da Piedade and Rodrigues present results of a parametric study, using a detailed network computer simulation, aimed at examining passive solar techniques used as building design concepts in Portugal. The techniques examined include thermal inertia, nocturnal ventilation and evaporative cooling. They concluded that by using these passive techniques comfort levels can be met in summer (hot/dry climate), and low levels of energy consumption can be achieved in winter.

Guppini et al. outline a guide produced for planning low energy residential housing. The guide combines the results of analysis and field experimentation in Europe. It aims at providing means for realizing building plans that optimizes comfort and energy consumption.

Guidelines must take economics into account, since an energy saving measure will not be used unless it is cost effective. Gustafsson and Karlsson present their findings of a study on minimizing life-cycle cost when retrofitting buildings. The methodology, applied to two buildings in Malmo, Sweden, considers a combination of envelope and heating system retrofitting. They present some guidelines for cost effective retrofitting for this climate. In general, they find that the lowest possible life cycle cost almost always emerges if a heating system with low running cost is implemented in the building. For low energy buildings, the initial cost of the heating system is also a factor. Windows are found to be mostly unprofitable to change for energy reasons alone.

2.3 Evaluation of Energy Analysis and Design Tools

With the many available energy analysis tools the question is, which one to choose? The merits of one versus another are often judged according to some combination of the following performance factors (2).

1. Accuracy: if modelled building and operating conditions were replicated in nature, how close would actual energy consumption be to that predicted by the model?

2. Sensitivity: can the analysis method show the effect, on energy consumption, of variation to the design alternative(s) to be considered?

3 Versatility: what fraction of real world buildings can be modelled and with what design features?

4. Speed: how long does it take to enter data for a building, and how long does the calculation take?

5. Reproducibility: if 100 users entered data for the same building, what would be the standard deviation of the results?

6. Ease of use: how difficult is it to learn to use the program, and how much preparation does it take to enter a building input?

There is always a conflicting demand between a number of these factors and the user should choose an analysis or design tool based on his own requirements. He may choose different tools for different jobs or purposes or at different stages of the design. For this reason the presentation by Clément et al. is quite relevant: an outline of a methodology for a common uniform presentation of building thermal modelling. This may be a better way to assist designers in choosing the appropriate analysis method.

A number of studies have attempted to compare energy analysis models, as for example, studies through the International Energy Agency IEA Task VIII. These include surveying analysis methods and design tools (3,4) and evaluation of detailed computer models (6) and simple design tools (7). In general, mostly due to time, resource and data limitations, all validation studies are limited. A collection of many of these studies may sometimes be needed to examine all aspects of building energy analysis techniques.

As mentioned, one of the limitations to many simplified analyses is their restrictions to treating a building as a single zone. The effect of this

assumption is examined in the paper by Pelletret. The predictions made by CSTB methods (Règles Th-K77, Th-G77 and Th-B85) of the thermal performance of a multi-zone (3 zone) building simplified to a single zone is compared to results predicted with a detailed network model. Differences of up to 30% (15% on the average) were observed between the annual heating requirements computed by the two methods, with the single zone model consistently underestimating the heating requirement. The results were used to improve the CSTB simplified method.

The paper by Eriksson et al. describes the work performed within IEA/ECB Annex XII to compare the annual heating requirement prediction of simplified energy analysis methods with each other and with a detailed computer model. Most of the simplified methods examined use the utilization factor approach to account for useful solar and internal gains. Several runs were made to examine the effects on the heating demand of varying the window size and orientation, the glazing type, the building mass, the inhabitant's behaviour pattern, and the heating control. Differences of up to 20% separate the results obtained by different methods. The authors explain these in terms of difficulties in calculating actual indoor temperature, solar heat gains and utilization factors for solar and internal gains. On the latter, some of the models use the same utilization factors for both solar and internal gains. A recent study (8) has shown that they can be quite different, and gives internal gain utilization factors for three different gain profiles.

Another analysis presented by Van de Perre and Gendt elaborates on the utilization factor correlation used in the Méthode 5000. Using a detailed simulation, the effect of a number of parameters on the utilization factor is examined and compared with Méthode 5000 correlation. The results have led them to suggest that the utilization factor depends on the heat gains and the set point in addition to the parameters already included. The dependence on heat gains is expected, due to the interaction between these gains and the building thermal mass.

Aghemo et al. present a comparison of capabilities and accuracy between two simplified methods, BILTE and the CSTB Règles Th-B85. Predictions by the two methods are compared to each other and to data collected on a number of buildings, one of which is completely instrumented. The authors conclude that for estimation of building energy consumption, these methods cannot reach precisions better than 10-15%, but they are more useful in evaluating the relative differences achieved by various design alternatives. Larger errors were noticed for "solar driven" buildings (with high gain-load ratio). These errors include all errors implicit in the experiments, all external errors (input data and weather) and internal errors of the analysis method itself.

2.4 Future Trends

The fast moving developments in microcomputers and the improvement in their speed and capacity are leading to a new look at analysis tools. The applications of computer-aided design (CAD) and knowledge-based systems in the area of building design and operation are growing (9). They will greatly improve the interface between the designer and his computer.

Current CAD systems incorporate several features that can be used or enhanced to serve as an interface with energy analysis tools. For example, graphic information about the building geometry, lay-out of the HVAC system, design details of envelope systems and attributes for components could all be

entered with a CAD system. It should then be possible to establish the link between the CAD system and energy analysis and design tools through data interface. Once this interface is established, the integration of other aspects of building performance becomes evident. These include thermal comfort, daylighting, air movement, indoor air quality and fire safety. Each of these aspects might require a new set of data or attributes to be added to the building details.

On the energy analysis side, the thermal analysis of the building would be combined with a ventilation and air movement analysis, as well as with HVAC system analysis to account for the obvious interaction. Some of this work is already taking place (10). The model 'ROYAL DEBAC', presented by Bryn and Harsem is also a step in this direction. The computer program makes it possible to take air stratification into account during the planning stage, along with energy analysis. This feature, as indicated in their paper, is particularly important for examination of local climate in large glazed spaces. This will also permit designers to observe the consequences of an energy related design decision on the quality of the indoor environment and vice versa.

In the area of Knowledge Based Expert Systems (KBES), several developments have emerged in a number of areas which can be used as examples for application in the building industry (11). Current examples for the use of KBES in buildings include operation, control and diagnostics of building systems, structural framing advisors and window diagnostic systems. KBES could be a powerful vehicle to transmit energy guidelines, whereby the designer can examine the impact of his design decisions on energy consumption and indoor environment, as well as meeting the requirement of applicable codes and standards. A powerful analysis method installed in the expert system, transparent to the designer, would perform the necessary calculations.

An example of the use of expert systems in the concept design stage of energy system design is presented by Doheny and Monaghan. Although their research mainly provides a basic framework for future developments, the preliminary stages of the implementation already include a limited group of energy systems. Other applications of KBES combined with energy analysis treat HVAC systems operation and diagnostics. The energy analysis provides the prediction of the "ideal" system performance and the expert system compares this to the actual performance (12). The operator is then led to diagnose problems or malfunctions when the HVAC system shows less than an optimum performance.

It is evident that emerging technologies will provide a mechanism for increasing the quality of decisions made during the building delivery and operation. Energy analysis should be an integral part of this development.

3. THEORY AND ANALYSIS OF ENERGY SAVING STRATEGIES

As mentioned earlier, a major use for energy analysis techniques is to examine design options and their effect on energy consumption. Repeated examination of a particular alternative would result in the development of the guidelines that designers could rely on without resorting back to detailed analysis at the early design stage.

One design option that is still being examined is the thermal storage capacity (thermal mass) of a building. The effect of thermal storage on annual energy consumption is examined for both continuous and intermittent heating by Esdorn et al. The calculation was done using a finite-element hourly program applied to apartment units in Berlin. For continuous heating, the reduction in annual energy consumption for individual apartment units due to additional thermal mass is found to be up to 25%, depending on the ratio of heat gains to heat losses. For entire apartment buildings, the overall reduction is up to 7%. On the other hand, for intermittently-heated buildings, the annual energy consumption usually increases with an increase in thermal storage, up to 5% for whole buildings. The result confirms conclusions presented earlier by Bianchi and Gilson.

Burch and Licitra extended their previous experimental findings on the thermal mass effect through a computer study to examine specifically the effect of partition walls and interior furnishings on the energy consumption in houses. The study uses the detailed energy analysis TARP for five locations in the USA. They conclude that the presence of additional mass has a small but beneficial effect on space heating and cooling loads. Larger effects were found for mild climate regions, where the house is operating near the balance-point temperature.

Escudie et al. use modeling to determine the effect of utilization and management of the heat provided by a "closed" fireplace on the energy consumption and interior temperature in a light and a heavy building. Their results also show the small but positive effect of thermal mass.

The work by Haugen et al. combines theoretical analysis and field experiments to examine the use of dynamic insulation in roof construction combined with a system for electrical heating and heat storage. The design is examined in both cold and hot weather conditions. The paper addresses the issues of air flow, condensation and heat storage, and indicates that the roof structure described is an interesting alternative for reducing daytime power peaks and total energy demands, especially for one-storey buildings.

Other uses of energy analysis techniques are demonstrated in the papers by Rozmiarek et al., and Peterson et al. The first uses a lumped parameter analysis to extrapolate test cell results, on the performance of a solar component, to other conditions and climatic locations. The latter uses DOE 2.1C computer simulation to propose an alternative approach to building energy performance standards. The analysis addresses multi-zone buildings and three generic HVAC system types.

4. ENERGY SAVINGS IN PRACTICE

4.1 Reduction of Energy Consumption

Building energy analysis methods are sometimes used in the form of energy auditing procedures to guide operators in efforts to reduce energy use in their existing buildings. Although energy auditing procedures are not addressed in this paper, it is worthwhile mentioning, that IEA Annex XI on Energy Auditing has produced a Source Book for Energy Auditors which contains valuable information on this subject (13).

A number of papers in this ICBEM Session deal with energy saving practices in a variety of building types. O'Donnell and Doukas present the results of integration and implementation of energy and maintenance programs at the World Trade Centre in Melbourne. The program has achieved a 15% reduction in energy consumption and a 12.7% reduction in cost within two years of implementation. Batty et al. indicate that an energy reduction of up to 40% of current values should be achievable in new catering establishments (in the UK) through improved building and services design and improved management of kitchens. Vale and Vale demonstrate how a small office building (for general practice surgery) can be built within strict cost limits and still achieve considerable energy savings (74% in space heating load and 80% in lighting load). Nilson presents the results of implementing energy conservation measures in nine blocks of flats in Sweden. Measurements were used to evaluate the savings and profitability from different combinations of such measures. Keller et al. present the design of a large public building in Switzerland. The design uses a combination of high insulation, passive solar concepts, an energy conserving heating system and an active domestic water heating system to reduce the total annual energy requirements to 153 MJ/m^2.

Pool and Brander have utilized their experience in reducing lighting energy use in a number of government buildings in New Zealand, to produce a guide for energy efficient lighting design and control.

Energy savings through the use of heat pumps are discussed in two different applications. Spante et al. report on the use of large capacity ground coupled heat pumps with a multiple well system for the heating of apartment buildings in Sweden. The system examined demonstrated that this is a viable option for a large number of apartment buildings in Sweden. In the heat pump application for heating service (or domestic) hot water, Gough reports on the effective use of a heat pump to produce hot water by removing heat from the chilled water return of an air conditioning water chilling system for an apartment building complex in Honolulu. This heat removal also contributed to a reduction of the cost of operating the chiller.

In another paper, Adnot and Rabl examine improvements to hot water heat pump systems to bring COP up to between 5 and 8 (compared to a conventional value of about 3). The two ideas proposed consist of lowering the temperature of the central system coupled with trace heating of the distribution pipes and modifications of the interface of heat pump and tank to allow optimal conditions for heat pump operation.

Looking at the future of energy conservation concepts, Kroner points to some indicators and developments which could lead towards entirely new concepts and definitions of building designs, building systems and energy-related technologies. Realizing that "incremental improvement" in the built-environment will remain a part of the future, he also lists some "leap improvements" or "visionary concepts" that suggest a different way of thinking about building research and design.

4.2 Occupant Interaction

Until recently, the occupant interaction was ignored in planning or performing building energy analyses. As Willey mentions in his paper, occupant were usually considered only in their role as receivers of the environment or technology. This is beginning to change with the realization

of indoor environment problems, whether related to thermal comfort, lighting or air quality. Particularly in commercial buildings, it is realized that energy costs are a very small fraction of the total cost of a building operation (including salaries). A number of studies are emerging to study the interaction between energy conservation, the indoor environment and the occupant. The general belief is that proper building design can achieve both energy conservation and good indoor environment.

Willey presents a number of design strategies for energy-efficient occupant control of the environment. This addresses the two perceived issues of occupant preference for some "naturalness" in the indoor environment and the desire to control it.

Williams and Crawshaw, on the other hand, discuss different ways to encourage occupants to save energy. They conclude that the route to more efficient behaviour lies in emphasizing the importance of cognition, not motivation. While education could improve energy management skills, they suggest that a more effective and practical solution would be to re-design controls (for more simplicity) and provide feedback to give the occupant the management tools to become more energy efficient.

Baird and Pool assessed the motivation underlying energy management in 22 commercial buildings in New Zealand. They discuss the role and impact of various levels of management and division of responsibility on the actual energy conservation measures and methods undertaken in these buildings. Croome and Cheslam report preliminary results of a study of occupant behaviour in two similar schools to explain a 30% difference in energy consumption. They highlight the role of management (the headmaster), as a "conservationist", a communicator and a problem solver, in affecting the energy conservation effort in a school.

The assessment of indoor environment depends on physical measurements as well as subjective occupant evaluations. The paper by Alberti proposes a method to evaluate human comfort-related performance of heating and conditioning systems. The method uses seven criteria to assess occupant complaints and relate them to the conditioning system, and to help the understanding of the technical reasons for satisfaction or dissatisfaction.

5. SUMMARY

Recent developments and uses of building energy analysis techniques, as represented by papers in this session on Building Planning and Design Tools, are discussed. The paper also summarizes presentations related to experiences with energy savings in practical applications and to the important role of occupants in realizing the energy savings.

It is evident by the number of papers in this session (63) that building energy analysis is still of considerable interest to the building research and building design communities worldwide. Current advances in computer-aided design and knowledge-based systems, and efforts to integrate them with more sophisticated energy analysis techniques, may lead to an increase in the use of building energy analysis during all stages of building design and operation.

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